Material Splitting by Near-Field Dual-Energy X-ray Phase Retrieval

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Summary: We apply linear iterative multi-grid phase retrieval for two energy phase contrast imaging, to improve signal to noise of the retrieved signal. Without making the single material assumption, we satisfactorily achieved two material separation in the projection space, to obtain the projected thickness of PMMA and Aluminum.

1. INTRODUCTION

Prior work has shown that propagation-based phase contrast imaging (PBI) with subsequent phase retrieval can improve the signal to noise (SNR) by up to hundreds and corresponding to dose reduction in the thousands [1]. This is of great importance for many applications in medicine and biology, where radiation exposure must be low while still getting suitable SNR. However, for satisfactory phase retrieval from one energy measurement, assumptions such as single material or pure phase object must be made about the investigated object [2]. To not have to make those assumptions, we use two measurements collected at the same propagation distance but with different X-ray energies. Phase retrieval is then performed by incorporating the Alvarez Macovski model that models the X-ray interaction as photoelectric and Compton scattering [3], this is mapped to the object attenuation and phase shift. This is the first time we apply it to monochromatic experimental X-ray projections and obtained a satisfactory material separation in the detector space, even when a third material is present. In this paper we show that linear iterative phase retrieval (LIPR) [4,5] keeps similar spatial resolution as no phase retrieval (NO PR), reduces phase contrast fringes, and improves the SNR. Furthermore, it allows us to separate our object into two known materials, in our case PMMA and aluminum.

2. EXPERIMENTAL METHOD

We used a simple object for our imaging experiments, shown in Fig 1a. It consists of PMMA (top and left), PVC (bottom), and aluminum (Al) (right) rods with a diameter of 3 mm each. X-ray imaging experiments were conducted at the SPring-8 Synchrotron in Hyogo, Japan, using monochromatic X-rays at 29 keV and 34 keV. We used a propagation distance of 500 mm A Hamamatsu digital sCMOS (C11440-22CU) detector with straight fibre optic and 6.5µm pixel size was used to record the images.

To allow for successful phase retrieval, the two projection images taken at different energies need to be aligned with sub-pixel precision [5]. After alignment we perform phase retrieval using the LIPR algorithm and No PR (LIPR with propagation distance = 0) to obtain maps of the projected density ($\int \rho =$ C) and projected density times atomic number cubed ($\int \rho Z^3 =$ P). LI-PR is a multi-grid solver, we run 16, 8, 4, 2 iterations with the corresponding down-sampling factor of 8, 4, 2, 1 respectively. With ρ being the physical density (g/ cm^3), and Z is the atomic number, we perform the material separation by calculating the thickness for each material by solving the following matrix equation:

$$\begin{bmatrix} C \\ P \end{bmatrix} = \begin{bmatrix} c_1 & c_2 \\ d_1 & d_2 \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \end{bmatrix}$$

where c_i and d_i for i=1,2 are equal to the material's ρ and ρZ^3, respectively. For Al we used $\rho = c_1 = 2.70$ g/cm^3 and $\rho{*}Z^3 = d_1 = 5932$ g/cm^3; for PMMA we used $\rho = c_2 = 1.19$ g/cm^3 and $\rho{*}Z^3 = c_2 = 321$ g/cm^3 [6].

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3. RESULTS

We show our results for separating PMMA and Aluminum (Al) in Fig 1 b) – e). Panels f) - k) show plots through relevant parts of the sample. From this we can see that both methods recover the correct thickness of the rods at approximately 3 mm in diameter. We notice that the result for aluminum is less noisy compared to that for PMMA, because aluminum is more attenuating than PMMA. For obtaining both Al and PMMA thickness, the LI-PR method results in less noise and less unwanted phase contrast fringes than without phase retrieval (No PR). We can trade this reduction in noise with shorter exposure time while keeping similar noise level.

We also took 1/4 and 1/16 of the total exposure time (in number of accumulations) to have 2x and 4x the amount of noise respectively for Al and PMMA. By comparing to the original No PR, we show LIPR with material separation has improved the signal to noise for both Al and PMMA, corresponding to a possible dosage reduction while retaining similar visual resolution and noise levels.

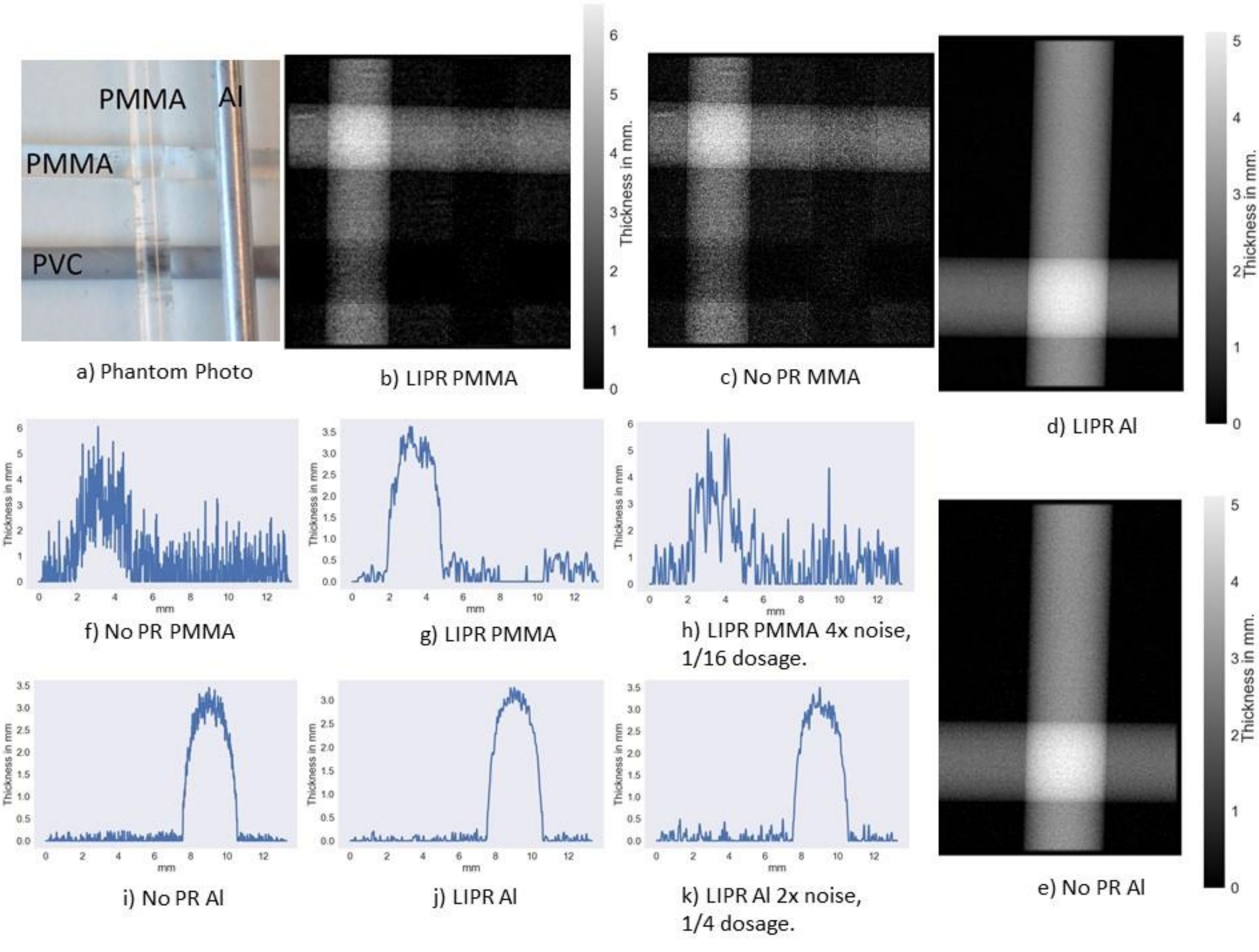

Figure 1: Phantom, and output in projected thickness of PMMA and Al to demonstrate the output for linear iterative phase retrieval (LIPR) compared to without phase retrieval (No PR).

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